EFFICIENT TECHNIQUE FOR ESTIMATING ELEVATION ANGLE WHEN USING A BROAD BEAM FOR SEARCH IN A RADAR

BACKGROUND

The invention relates generally to radar systems.

In ground-based search radar systems with rotating (360°) antennas, a broad fan beam or shaped beam, e.g., a cosecant-squared beam, can be used to efficiently search over large elevation angles. This type of approach to searching for a target over a large angular search area is less time consuming than a single sequential beam approach. Typically, an elevation monopulse channel and an azimuth monopulse channel provide an accurate estimate of elevation angle and azimuth angle, respectively, for a target detected by narrow pencil beams. Unfortunately, accurate elevation estimates cannot be obtained for a target detected by the broad beam. One solution to this problem is to use a stacked beam on receive. The use of a stacked beam is costly, however, as it requires one or two receivers for each beam in the stacked beam.

SUMMARY

The present invention is therefore directed towards a mechanism for efficiently determining elevation angle information of a target detected in elevation with a broad beam such as a cosecant-squared beam.

In one aspect, therefore, the present invention provides methods and apparatus for determining target elevation during a radar search. The methods include determining the range of any target detected during a search with a broad beam covering a broad angular search area and, based on the determined range, transmitting consecutive beams at increasing search elevation angles in the broad angular search area and using echo signals of the consecutive beams to obtain an elevation angle estimate for the target.

Embodiments of the invention may include one or more of the following features.

The broad beam can be a shaped cosecant-squared beam.

The consecutive beams can be transmitted sequentially in time.

The first of the consecutive beams (the one at the lowest elevation angle) can be focused. Alternatively, it can be slightly defocused. The succeeding beams at successively higher elevation angles can be defocused by spoiling factors that increase with the increasing search angles. Typically all but the first one of the consecutive beams is defocused.

For a pulse Doppler radar, the transmission of the consecutive beams can include transmitting a pulse Doppler waveform which includes a set of transmit bursts, each transmit burst including a number of sub-pulses. Consecutive groups of subpulses in each transmit burst correspond to the consecutive beams. Corresponding numbered sub-pulses in each of the transmit bursts of the set have the same carrier frequency. The sub-pulses in each transmit burst can have different carrier frequencies. It is, however, possible although not generally preferred, to have the same carrier frequencies for different groups (or bursts) of sub-pulses.

Using the echo signals includes processing echo signals of the first one of the consecutive beams to detect the target. If the target is detected, an elevation angle estimate for the target is determined. Using the echo signals further includes (i) processing, in turn, echo signals of the defocused consecutive beams in the sum and difference channels until the target is detected in one of the defocused consecutive beams; (ii) using the results of the processing of the echo signals of the one of the defocused consecutive beams in which the target is detected to provide a first estimate of the elevation angle of the target; (iii) transmitting a focused beam towards the target based on the first estimate; and (iv) processing echo signals of the focused beam in the sum and difference channels to detect the target and determine a second, more accurate estimate of the elevation angle of the target.

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Particular implementations of the invention may provide one or more of the following advantages. The search mechanism is quite efficient in that it makes use of the knowledge of the range of the target and the radar system's elevation scan capability together with a time multiplexed waveform to obtain a more accurate determination of the target elevation. The time multiplexed waveform transmits pulses at different elevation angles to look for the target during one dwell time. These pulses use defocused beams. The defocusing is increased with the degree of the elevation angle being searched. Such defocusing is possible and desirable because the range to the detected target decreases with increasing elevation angle. The defocusing is needed in order to efficiently cover the elevation uncertainty angle which one has after detecting the target with the cosecant-squared beam or the fan beam. Once the target is located with the defocused beam, a focused beam is used to get the final, highly accurate elevation angle estimate. With an antenna having an azimuth look-back capability, it is possible to do the dwells with the defocused and focused beams during the same rotation period as that in which the target is detected. Thus, the approach of the present invention provides for efficient searching above a certain low elevation angle, e.g., six degrees (or even zero degrees), without adversely impacting search frame time as with the conventional single sequential beam approach.

Other features and advantages of the invention will be apparent from the following detailed description and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram of a pulse Doppler monopulse radar system.

FIG. 2 is depiction of transmit and receive beams used by the monopulse radar system of FIG. 1 for search coverage from 0 to 70 degrees.

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FIG. 3 is a flow diagram of the operational flow of a broad beam target search that uses an elevation angle determination process for determining elevation angles for targets detected in higher elevation.

FIG. 4 is a flow diagram of the elevation angle determination process (of FIG. 3) for a single detected target.

FIG. 5 is an illustration of the waveform used during the elevation angle determination process from FIG. 4.

FIG. 6 is a detailed block diagram of the detector block of FIG. 1.

FIG. 7 is a flow diagram of the elevation angle determination process for multiple detected targets.

Like reference numerals will be used to represent like elements.

DETAILED DESCRIPTION

Referring to FIG. 1, a radar system 10 is shown. The radar system 10 may be a ground-based radar system, but could be used on a ship, aircraft or spacecraft as well. The radar system 10 includes a transmitter 12, the output of which is delivered to an antenna 14 (in an antenna system 16) for radiation in the form of a transmit beam. The antenna 14 collects echo signals received from a target and a combiner 18 (also in the antenna system 16) combines the echo signals into receive signals 20, which are processed by a receiver 22 to detect the presence of the target and determine its location in range and in angle. In the illustrated embodiment, the antenna 14 is a mechanically rotating antenna to scan in azimuth. However, the antenna 14 could also be an electronically scanned in azimuth antenna. A duplexer 24 coupled to the transmitter 12, receiver 22 and antenna 14 allows the antenna 14 to be used on a time-shared basis for both transmitting and receiving.

Still referring to FIG. 1, the receiver 22 includes a receiver block 30 to perform RF-to-IF conversion, amplification, A/D conversion, possibly pulse compression filtering, as well as includes a detector block 32 and a monopulse processing block 34. The detector block 32 detects the presence of the target. More specifically, the detector block 32 performs Discrete Fourier Transforms (DFTs), envelope detection and post-detection integration (video integration), among other functions. The monopulse processing block 34 produces angle information 35 from the output of the detector block 32. The angle information includes information indicative of estimated elevation angle and azimuth angle.

In the illustrated embodiment, the receiver 22 is a monopulse receiver. Thus, receive signals 20 include three signals, a sum (S) signal 36, an elevation difference ("ΔEL") signal 38 and an azimuth difference ("ΔAZ") signal 40. The receiver block 30 and the detector block 32 can be partitioned into three separate channels, one for each of the signals 36, 38 and 40, respectively. Thus, receiver block 30 includes receiver blocks 48, 50 and 52, and detector block 32 includes detector blocks 54, 56 and 58. The receiver block 48 and detector block 54 form a sum channel to process the sum signal 36. The receiver block 50 and detector block 56 form an elevation difference channel to process the elevation difference signal 38. The receiver block 52 and the detector block 58 forms an azimuth difference channel to process the azimuth difference signal 40.

The sum channel is further coupled to a threshold detect unit 60, which generates a range signal from the output of the sum channel's detector block 54. The receiver 22 also includes a detection verification block 62 as well as a range and Doppler ambiguity removal block 64. Although not shown, the receiver 22 may be coupled to a tracker.

The output of the monopulse processing block 34 is connected to a controller/interface 68. The controller 68 provides control signals 70 to functional blocks of the system 10. In

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particular, the controller 68 enables the system 10 to perform a target search at higher elevation using a broad search beam, and to determine an accurate elevation angle estimation of a target detected by such a broad search beam, as will be described.

A "broad" elevation search beam, that is, a beam that covers a broad elevation angular search area, is a defocused (or spoiled) beam that is at least as wide as the combined beamwidths of two focused beams. Typically, however, it is much wider. A "focused" beam is a beam that has no phase modulation (for the illumination across the antenna) in the vertical direction, resulting in a beamwidth in elevation of approximately λ/H, where H is the height of the antenna. In contrast, a "defocused" beam is a beam that has phase modulation in the vertical direction. For example, a defocused beam could have a quadratic-like phase modulation.

Those aspects of the radar system 10 not described herein can be implemented according to known radar techniques, for example, those found in the "Aspects of Modern Radar," edited by Eli Brookner, (Artech House, Inc., 1988), incorporated herein by reference, and other sources. For example, monopulse techniques are discussed at some length in Chapter 5, pages 297-335, of the above-referenced Brookner text.

During a target search, the antenna 14 transmits one of two different types of beams depending on search elevation. Referring to FIG. 2, exemplary search coverage 80 includes on transmit two narrow beams 82 ("beam 1") and 84 ("beam 2") and a broad search beam 86 ("beam 3"). The narrow beams 82, 84 are used for searching at low elevation angle (e.g., from the horizon up to 5.6° in elevation, as shown) at long range. For an efficient higher elevation search, for example, when searching elevation angles from 5.6° up to 70°, the broad beam 86 is used. The broad beam 86 can be a beam such as a cosecant-squared ("CSC^2") shaped beam (as illustrated), which is a recognized beam pattern for searching large angular volume. The lower beams 82 and 84 use all three channels, in particular, the sum channel to detect the target and

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elevation and azimuth monopulse receive channels to provide estimates of the target azimuth ("AZ") and elevation ("EL") angles. The broad beam 86, e.g., the CSC^2 beam, does not use AZ or EL monopulse. Therefore, the broad beam 86 does not provide any EL angle estimates. Consequently, the beam 86 obtains good elevation coverage at the sacrifice of elevation angle measurement accuracy. Furthermore, it has the important advantage of providing the large angle coverage with only three receivers, thus lowering cost. Finally, the broad beam provides such large angular coverage in a short time, thus allowing a fast volume revisit time.

In one embodiment, when illuminating the search volume with the broad beam, the two channels ordinarily used on receive for the AZ and EL monopulse with beams 1 and 2 are also used for focused receive beams 88 and 90 ("beam 3A" and "beam 3B") to provide better long range coverage in a lower elevation search area of the broad beam 86, for example, in the illustrated embodiment, between the angles 5.6°and 11.2°. They also provide some elevation angle estimation, specifically, if the target is detected in either of these focused receive beams 88 and 90, an initial rough estimate of its elevation angle is available. The amplitude of the returns in the two receiver channels associated with these two beams give some indication of the target's location in elevation. That is, elevation amplitude monopulse estimates can be obtained from the outputs of beams 88 and 90. When such an estimate is available, the system 10 transmits a focused beam in the direction of the target's location. This focused transmit beam has monpulse AZ and EL, and provides an accurate estimate of the target's EL and AZ angles. A pulse Doppler waveform whose pulse repetition frequency ("PRF") has no range and Doppler eclipsing could be used for the focused transmit beam. If it is determined that the target is not detected by beams 3A or 3B (which provide coverage between angles 5.6° and 11.2°), the system 10 uses a special elevation angle estimation process involving additional transmit beams, including beam 92 (beam 1C), beam 94 (beam 2C), beam 96 (beam 3C), beam 98 (beam 4C) and